PREDICTIONS OF MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT FROM SIMPLE MATERIAL PROPERTIES

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ABSTRACT

A set of results of basic soil classification properties, particle size distribution, plasticity and corresponding compacted maximum dry density and optimum moisture content tests recorded on Australian soils was analysed to establish equations to predict the last two parameters from the classification data. A stepwise variable selection linear regression analysis gave the best results for the Australian data analysed. Models developed by other workers and a simplification of those models did not give a closer prediction for the Australian soil dataset.

1. INTRODUCTION

The ability to determine the properties and construction suitability of potential road base materials without the need for extensive laboratory testing will reduce time and costs. A portable road base test kit for simple tests to attain a preliminary assessment of material suitability for low-volume road pavements has been assembled with a software package which calculates basic classification parameters. The compacted density test requires extensive testing time and equipment and could be avoided if models were available to estimate maximum dry density (MDD) and optimum moisture content (OMC) using the soil parameters acquired through simple tests. The purpose of this paper is to describe a limited analysis of available Australian soil test data to develop prediction equations for the maximum modified dry density and optimum moisture content.

2. PREVIOUS FINDINGS

A literature review for other sources of previous work on correlations of soil parameters was conducted. Various in situ tests were found to determine different soil parameters including bulk density, shear strength, California Bearing Ratio and bearing capacity. However, the only source predicting MDD and OMC through simple tests was [1]. Their study produced the following correlations between gradation, plasticity and optimum moisture content and density:

2.1 Modified Proctor Compaction Effort

For soils with plastic fines (n = 58 samples)

$$\text{MDD (pcf)} = 131.06 - 0.84733*\text{PL} + 0.31392*\text{GSP} \qquad [1]$$

or $$\text{MDD (t/m}^3\text{)} = 2.1 - 0.0136*\text{PL} + 0.00503*\text{GSP}$$

$$\text{OMC (\%)} = 6.8455 + 0.36895*\text{PL} - 0.10135*\text{GSP} \qquad [2]$$

For soils with non-plastic fines (n = 26 samples):

$$\text{MDD (pcf)} = 102.07 + 0.46044*\text{GSP} \qquad [3]$$

or $$\text{MDD (t/m}^3\text{)} = 1.636 + 0.00738*\text{GSP}$$

$$\text{OMC (\%)} = 12.247 - 0.068758\ \text{GSP} \qquad [4]$$

where:

OMC = Optimum Moisture Content (%)

MDD = Maximum Dry Density (pcf or t/m^3)

PL = Plastic Limit

GSP = Grain size parameter (see equation (8) in [1]).

3. SOIL DATA

The data used in this paper was collected in Australia by Ingles and Metcalf [2]. The properties measured included soil grading, plastic limit, linear shrinkage, plasticity index, maximum modified dry density and optimum moisture content. The full data set consists of observations on 71 soils from which a subset of 25 observations were selected with plasticity indices between 0 and 40.

Different methods were adopted to predict maximum dry density and optimum moisture content from the following selected independent variables:

P19 = % passing 19 mm sieve,

P2.36 = % passing 2.36 mm sieve

P0.075 = % passing 0.075 mm sieve

Plastic Limit (PL)

Linear Shrinkage (LS)

Plasticity Index (Ip)

The percentage passing for sieves 26, 2.00, 0.425 mm were interpolated using the following relationships:

P26 = MIN [P2.36 + (P19 – P2.36)*(260.5 – 2.360.5) / (190.5 – 2.360.5), 100] [5]

P2 = P0.075 + (P2.36 – P0.075) * (20.5 – 0.0750.5) / (2.360.5 – 0.0750.5) [6]

P0.425 = P0.075 + (P2.36 – P0.075) * (0.4250.5 – 0.0750.5) / (2.360.5 – 0.0750.5) [7]

The following parameters were then estimated and used in the regression analyses.

Grain size parameter, GSP:

GSP = 100 – (P9.5 + P4.75 + P2 + P0.425 + P0.15 + P0.075) / 6 [8]

Grain size parameter as adopted for this study, GSP#:

GSP# = 100 – (P19 + P2.36 + P0.425 + P0.075) / 4 [9]

Gradient Coefficient:

GC = P4.75 * (P26 – P2) / 100 [10]

Gradient Coefficient as adopted for this study, GC#:

GC# = P4.75 * (100 – P2.36) / 100 [11]

Grading modulus:

GM = (300 – (P2.36 + P0.425 + P0.075)) / 100 [12]

NSW Grading ratios:

GR1 = P0.425 / P2.36 and GR2 = P0.075 / P0.425 [13]

Shrinkage Product (SP): SP = LS * P0.425 [14]

Fines Ratio (FR): FR = P0.075 / P2.36

Plasticity product (PP): PP = Ip x P0.075 [15]

Plasticity Modulus (PM) PM = Ip x P0.425 [16]

Predicted Ip (Ipe) Ipe = 2.13 LS [17]

Dust ratio (DR) DR = P0.075 / P0.425 [18]

4. REGRESSION MODEL DEVELOPMENT

Multiple linear regressions of the following general format were studied:

$$Y = a0 + a1\,X1 + a2\,X2 + + am\,Xm + e \quad [19]$$

where: Y = the dependent variable

Xm = the mth independent variable

a0 = the intercept

am = the partial regression coefficient for the mth independent variable

e = the error in the model

For this investigation, the maximum modified dry density and the optimum moisture content were the dependent variables. The results are based only on the plastic soil subset. The same methods were used in an attempt to represent the non-plastic data, but no significant relationships were found due to the limited amount of data available.

Forward stepwise variable selection in linear regression analysis was used in this analysis. It provided the linear regression model which contains only the independent variables that make a significant contribution to predicting the dependent variable. The Coefficient of Determination and the Significance are the indicators of the goodness of fit of the developed model. The Coefficient of Determination (R^2 value) is the proportion of variability accounted for by the statistical model. Significance (F) is the level of overall statistical significance for the model. It is generally considered that if Significance (F) is less than 0.05 the regression model is statistically significant.

5. RESULTS

5.1 First Analysis – Linear Regression of All Defined Variables

The results of the first analysis, linear regression of all defined variables, are now reported.

5.1.1 Maximum Modified Dry Density

$$MDD\ (t/m^3) = 2.0513 - 0.0114*PL - 0.00016*PM + 0.2901*GR2 \quad [20]$$

where PL = Plastic Limit

PM = Plastic Modulus = Ip * P0.425

GR2 = P0.075 / P0.425

R^2 = 0.8061 and Standard Error = 0.074 (t/m^3)

F = 29.1 Significance(F) = 1.13E-07

The measured MDD and the values predicted by equation 20 are given in Figure 1.

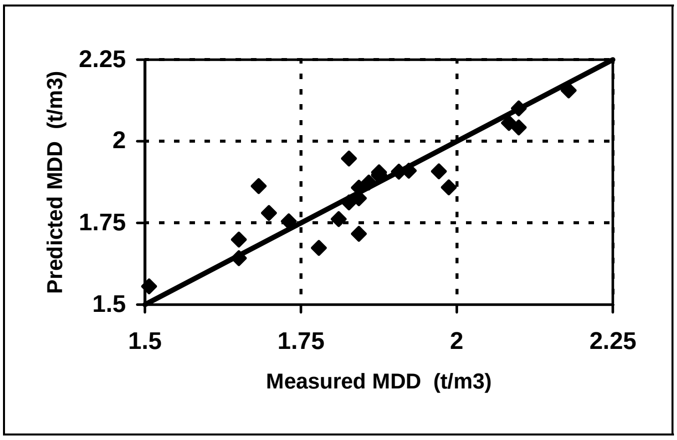

Figure 1: Predicted vs. measured MDD (Equation 20)

5.1.2 Optimum Moisture Content

$$\text{OMC (\%)} = 9.4169 + 0.0041*PM - 0.3095*GC + 0.3107*PL \qquad [21]$$

where PL = Plastic Limit

PM = Plastic Modulus = Ip * P0.425

GC = Grading coefficient (eqn 10)

R^2 = 0.7818 and Standard Error = 2.46 (% moisture)

F = 25.08 Significance(F) = 3.87E-07

The measured OMC and the values predicted by Model 21 are shown in Figure 2.

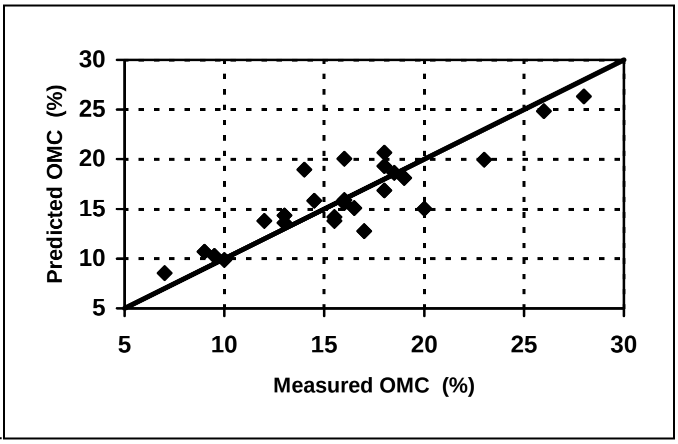

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Figure 2: Predicted vs. measured OMC – Equation 2

5.2. Comparison With Existing Models

In a second approach the parameters used by Berney & Wahl [1] were calculated for the Australian dataset and used as independent variables. The following models were obtained:

5.2.1 Maximum Dry Density

$$\text{MDD (t/m}^3) = 1.74 - 0.00983*PL + 0.00727*GSP \qquad [22]$$

where GSP = 100 – (P9.5 +P4.75 + P2 + P0.425 + P0.15 + P0.075) / 6

and R^2 = 0.7913 and Standard Error = 0.0875 (t/m^3).

The measured MDD and the values predicted by equation (22) are given in Figure 3.

5.2.2 Optimum Moisture Content

$$\text{OMC (\%)} = 20.8 + 0.2678*PL - 0.2344*GSP \qquad [23]$$

where GSP = 100 – (P9.5 +P4.75 + P2 + P0.425 + P0.15 + P0.075) / 6

and R^2 = 0.6982 and Standard Error = 2.83 (% moisture)

The measured OMC and the values predicted by eqn (23) are shown in Figure 4.

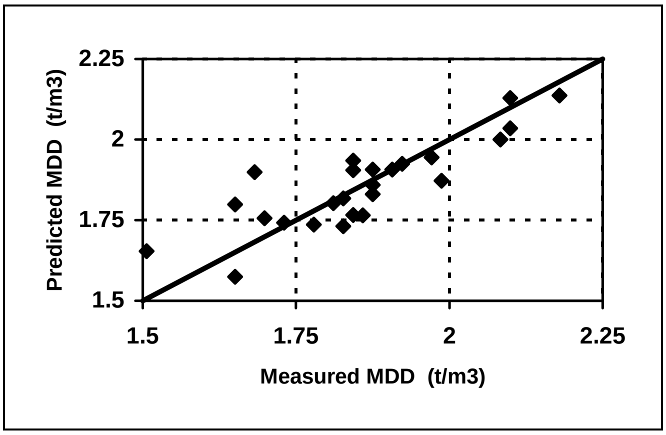

Figure 3: Predicted MDD vs. measured MDD – Equation 22

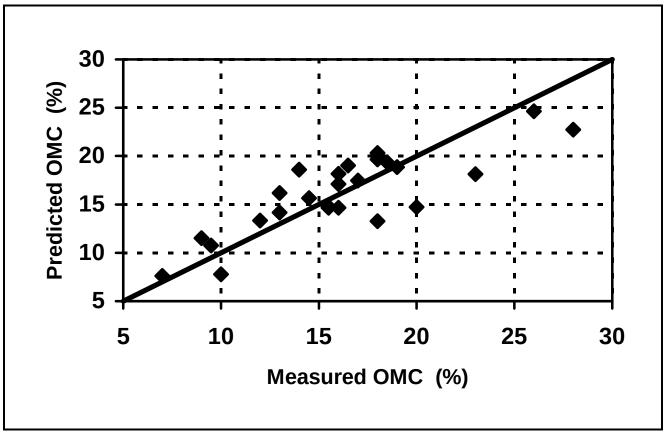

Figure 4: Predicted OMC vs. measured OMC – Equation 23

5.3. Third Method – Modified GSP Parameter

In a third method, the GSP parameter used by Berney & Wahl [1] was modified. In the new form, GSP# is computed using the per cent retained for only four sieves instead of six. This analysis resulted in the following models:

5.3.1. Maximum Dry Density

$$\text{MDD (t/m}^3) = 1.761 - 0.0101*PL + 0.008*GSP\# \qquad [24]$$

where GSP# = 100 – (P19 + P2.36 + P0.425 + P0.075) / 4

and R^2 = 0.7035 and Standard Error = 0.09 (t/m^3).

The measured MDD and the values predicted by equation (24) are given in Figure 5.

5.3.2. Optimum Moisture Content

$$20.08 + 0.2782 * PL - 0.2559 * GSP\# \qquad [25]$$

where GSP = GSP# = 100 – (P19 +P2.36 + P0.425 + P0.075) / 4

and R^2 = 0.6737 and Standard Error = 2.95 (% moisture)

The measured OMC and the values predicted by eqn (23) are shown in Figure 6.

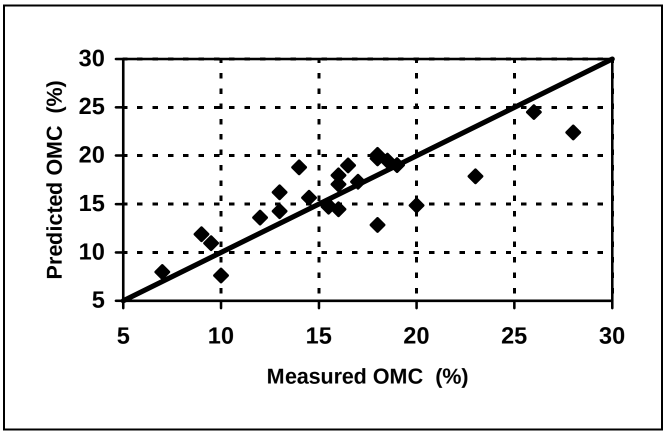

Figure 5: Predicted MDD vs. measured MDD – Equation 24

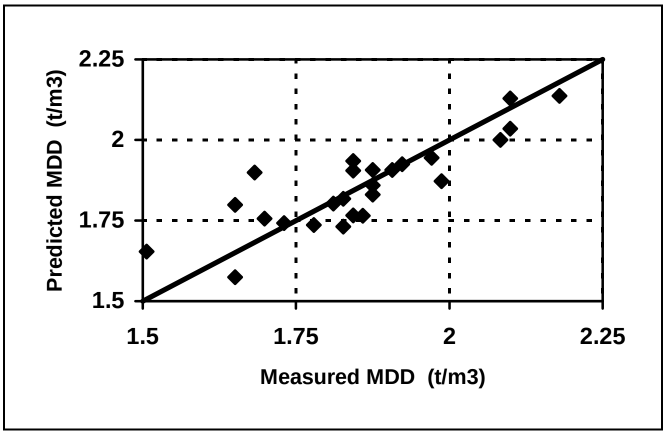

Figure 6: Predicted vs. measured OMC – Equation 25

6. CONCLUSION

A stepwise forward variable selection regression procedure was used to predict MDD and OMC from Australian data. The independent variables tested includes percentage passing each of seven sieves: 19 mm, 4.75 mm, 2.8 mm, 2.36 mm, 2.00 mm, 0.425 mm, 0.075 mm, and the parameters Grain Size Parameter, Plastic Limit, Linear Shrinkage, Plasticity Index, Shrinkage Parameter, Grading Coefficient, Fines Ratio, Binder Index, Plasticity Modulus, Predicted Plasticity Index, Dust Ratio and Grading Modulus. The number of observations in the dataset was 25.

The best fit to the data yielded the following equations below:

$$MDD\ (t/m^3) = 2.0513 - 0.0114*PL - 0.00016*PM + 0.2901*GR2 \quad [20]$$

$$R^2 = 0.81;\ \text{Standard Error} = 0.074\ (t/m^3)$$

$$OMC\ (\%) = 9.4169 + 0.0041*PM - 0.3095*GC + 0.3107*PL \quad [21]$$

$$R^2 = 0.78;\ \text{Standard Error} = 2.46\ (\text{moisture})$$

This method gave better correlation than the two other approaches derived from equations containing the parameters used by Berney and Wahl [1] which give only moderate to low predictions for MDD and OMC for Australian soils. More accurate predictions can be achieved using the new equations generated from Australian data.

The two Barney and Wahl [1] models, with original or modified independent variables, gave very similar R^2 values (0.72 and 0.65) and standard errors (0.0875 and 0.09 t/m^3) for MDD. The R^2 values

(0.698 and 0.674) and standard errors (2.83 and 2.95%) were very similar for the OMC prediction equations. Therefore, a Grain Size Parameter value derived from four sieves, instead of six sieves, had a minimal effect on the accuracy of the prediction of MDD.

It is important to note here that the recommended equations give only a moderate to strong fit for MDD and a moderate fit for OMC. Therefore further analysis on an expanded data set containing additional data could further enhance the effectiveness of the prediction models.

REFERENCES

1. Berney, ES and Wahl, RS, Rapid soils analysis kit for low-volume roads and contingency airfields, Transportation Research Record No. 1989, pp. 71-78. Transportation Research Board (TRB), Washington DC, 2007.

2. Ingles, OG and Metcalf, JB, *Soil Stabilization – Principles and Practice*, Butterworth, Sydney, 1972.